Example 2b: Strain-Rate Dependence of Ti-21S

This example problem examines the elevated temperature strain rate (SR) dependence of two different constitutive models for the same material, namely Ti-21S. Ti-21S is associated with both the isotropic GVIPS viscoplastic constitutive model and the modified Bodner-Partom (MBP) viscoplastic constitutive model in the MAC/GMC 4.0 internal material database (see the Keyword Manual Section 2). Both models incorporate strain rate dependence, but, as this example shows, the elevated temperature inelastic behavior of Ti-21S predicted by each of these models is different. The applied strain rate is altered from 10^{-4}/sec. to 10^{-5}/sec. to 10^{-6}/sec. by commenting and uncommenting the appropriate lines under ***MECH** and ***SOLVER**.

MAC/GMC Input File: example_2b.mac

```
MAC/GMC 4.0 Example 2b - Strain Rate Dependence of Ti-21S
*CONSTITUENTS
  NMATS=2
# -- Ti-21S Isotropic GVIPS
  M=1 CMOD=4 TREF=650. MATID=A
# -- Ti-21S MBP
  M=2 CMOD=2 TREF=650. MATID=A
*RUC
  MOD=1 M=1
#  MOD=1 M=2
*MECH
  LOP=1
  NPT=2 TI=0.,20. MAG=0.,0.02 MODE=1
#  NPT=2 TI=0.,200. MAG=0.,0.02 MODE=1
#  NPT=2 TI=0.,2000. MAG=0.,0.02 MODE=1
*SOLVER
  METHOD=1 NPT=2 TI=0.,20. STP=0.0025
#  METHOD=1 NPT=2 TI=0.,200. STP=0.025
#  METHOD=1 NPT=2 TI=0.,2000. STP=0.25
*PRINT
  NPL=0
*XYPLOT
  FREQ=200
  MACRO=1
   NAME=example_2b X=1 Y=7
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (***CONSTITUENTS**) [KM_2]:

Number of materials:	2	(NMATS=2)
Constitutive models:	Isotropic GVIPS	(CMOD=4)
	Modified Bodner-Partom	(CMOD=2)

Materials:	Ti-21S	(MATID=A)
Reference Temperature:	650. °C	(TREF=650.)

3) Analysis type (***RUC**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Monolithic material	(MOD=1)
Material assignment:	Each constituent successively	(M=1,2)

Each of the two materials in ***CONSTITUENTS** is assigned to the monolithic material successively by commenting and uncommenting the appropriate lines.

4) Loading:

a) Mechanical (***MECH**) [KM_4]:

Loading option:	1	(LOP=1)
Number of points:	2	(NPT=2)
Time points:	0., 20. sec.	(TI=0.,20.)
	0., 200. sec.	(TI=0.,200.)
	0., 2000. sec.	(TI=0.,2000.)
Load magnitude:	0., 0.02	(MAG=0.,0.02)
Loading mode:	strain control	(MODE=1)

☞ Note: By altering the time points in the mechanical loading history, the global strain rate is decreased from 10^{-3}/sec. to 10^{-4}/sec. to 10^{-5}/sec.

b) Thermal (***THERM**): None

c) Time integration (***SOLVER**) [KM_4]:

Time integration method:	Forward Euler	(METHOD=1)
Number of time points:	2	(NPT=2)
Time points:	0., 20. sec.	(TI=0.,20.)
	0., 200. sec.	(TI=0.,200.)
	0., 2000. sec.	(TI=0.,2000.)
Time step sizes:	0.0025 sec.	(STP=0.0025)
	0.025 sec.	(STP=0.025)
	0.25 sec.	(STP=0.25)

As in Example 2a, the very small time step sizes employed in this example are due to the stiff nature of the modified Bodner-Partom equations. A much larger step size can be used for the GVIPS cases presented in this example.

5) Damage and Failure: None

6) Output:

a) Output file print level (***PRINT**) [KM_6]:

Print level:	0	(NPL=0)

b) x-y plots (***XYPLOT**):

Frequency:	200	(FREQ=200)
Number of macro plots:	1	(MACRO=1)

Macro plot name:	example_2b	(`NAME=example_2b`)
Macro plot x-y quantities:	ε_{11}, σ_{11}	(`X=1 Y=7`)
Number of micro plots:	0	(`MICRO=0`)

7) End of file keyword: (**`*END`**)

Results

The results for this example problem are shown in Figure 2.2. While the qualitative effect of changing the strain rate is similar for both Ti-21S constitutive models, the predicted stress-strain curves at each strain rate are somewhat different quantitatively. This demonstrates that the different constitutive models within MAC/GMC 4.0 give different results, even for the same material. For an illustration of the impact of these types of constitutive model differences, see Bednarcyk and Arnold (2002).

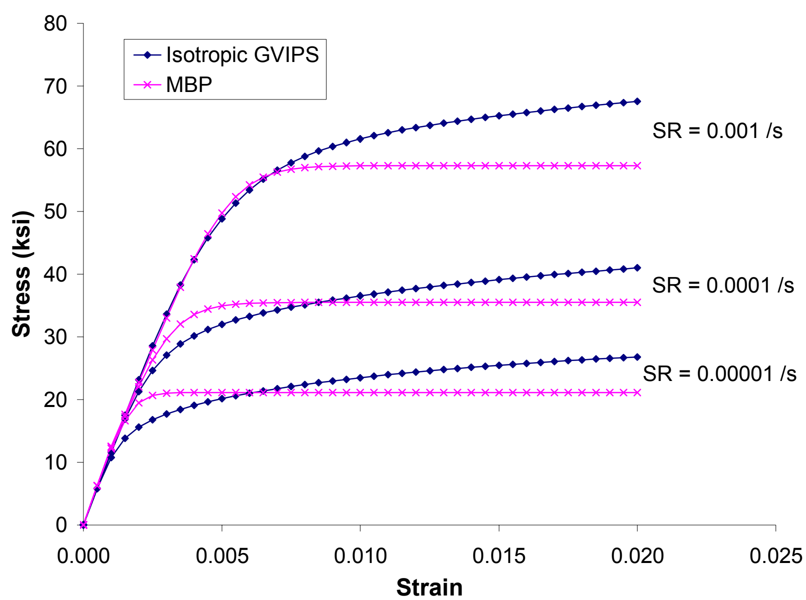

Figure 2.2 Example 2b: plots of the tensile stress-strain response of Ti-21S at 650 °C as modeled by the isotropic GVIPS and modified Bodner-Partom (MBP) constitutive models as a function of the applied strain rate (SR).